Cost & Business Model Analysis for Civilian UAV Missions

Final Report

Prepared for:

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Earth Science Enterprise

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Executive Summary

Overview

This study identified and evaluated potential business models for private companies to provide affordable UAV flight services for NASA science missions over the next five years (2005 – 2009).

Business Perspective of UAV Science Missions

Civil science missions do not efficiently use manned or unmanned aircraft. This is the inherent nature of conducting experimental science. Aircraft are committed for long periods in which they fly relatively few hours. Using standardized payload pods and pallets will reduce the non-flying time aircraft are needed for science missions.

UAV civil science operations are, and will remain, a niche market in the US. Most US UAV manufacturers, including those that once focused on civil UAVs, are now focused on building military business.

Past UAV science mission costs do not reflect the true cost of UAV operations. NASA has primarily used developmental UAVs for science missions. Past NASA UAV mission costs have not included amortization of vehicle and ground station acquisition costs. These costs must be recovered by a commercial UAV flight service. Amortization (or lease) costs will be about 50% of a commercial UAV flight service's expenses.

Evaluating UAV-related science mission costs in terms of marginal cost per flight-hour ignores most of UAV-related costs. For science missions, the UAV marginal cost per flight-hour is only 25 – 30% of total cost for flight services. The remainder are mission peculiar costs. A more useful cost metric is *flight service cost per mission,* which includes marginal operating costs and mission peculiar costs.

There may be near term opportunities to reduce UAV flight service costs. Insurance costs might be reduced by increasing awareness and stimulating competition in the insurance industry. Lower satcom costs might be possible by leveraging GSA and DoD satcom service contracts.

Providing NASA PIs with better business information and resources should result in higher quality UAV flight services at a lower price. Standardized cost reporting can create information that PIs and NASA managers can use to reduce uncertainty in cost estimates and obtain better prices for flight services.

Future UAV Science Missions

No one type of UAV can satisfy most of the anticipated demand for science missions. Requirements range from Aerosonde to Global Hawk-class UAVs. Some UAV demand is now being satisfied with new manned aircraft, such as the Proteus.

The High Altitude, Long Endurance (HALE) regime is the only practical niche for NASA to transition to UAV flight services. Aerosonde Pty. Ltd. is already providing flight services for small long endurance UAVs. CIRPAS is satisfying needs for mid altitude UAVs.

Altair® is the only HALE UAV available from US industry that is practical for near term airborne science missions. This reinforces GA-ASI's dominant market position. Any plan for transition to commercial flight services must consider how GA-ASI will respond.

A commercial (for-profit) HALE UAV flight service using the Altair® is a viable approach to satisfy NASA's emerging science needs. A non-profit flight service might have somewhat lower prices for NASA, but has greater uncertainty in long term service quality and operational capability.

Flight service costs are sensitive to UAV and ground equipment acquisition costs. Competition among UAV manufacturers is desirable. If this is not possible, other innovative approaches might be possible, such as equipment leasing.

Making multi-year commitments for UAV flight services will lower costs. This would allow a UAV flight service provider to sign long-term leases for its UAVs and ground equipment, which should reduce annual expenses. Conversely, short-term lease would probably result in substantially higher flight service costs.

Flight service costs for NASA UAV science missions can be significantly reduced by attracting other customers. Desire for higher profits should motivate a commercial flight service to pursue other customers. A non-profit flight service will not have this motivation.

Global Hawk flight service costs are about three times higher than Altair®, if both aircraft fly the same number of missions. Global Hawk may have more payload capacity and performance than needed to satisfy most science requirements — unless it replaces the ER-2. Using Global Hawk for UAV science missions will involve managing multiple payloads on one flight. Today, this capability only resides in the government. Transferring this capability to a commercial flight service may involve significant cost and technical risk.

NASA's airborne science program could establish technology goals that lead to significant long-term reductions in UAV flight service costs. Possible goals are reducing the required bandwidth for over-the-horizon communications, developing innovative ways to exploit new low cost satellite communications services (such as Connexion by Boeing℠), and improving UAV reliability. Technological synergies in the next generation of small UAVs could lead to a substantial reduction in UAV science mission costs.

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Administrative Information

This is the final report of a study entitled, "Cost & Business Model Analysis for Civilian UAV Missions." Moiré Incorporated performed the study with the assistance of Longitude 122 West, Incorporated under contract to the San Jose State University Foundation. Funding was provided by the Suborbital Science Office in NASA's Earth Science Enterprise through the Earth Science Division of NASA Ames Research Center.

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Abbreviations & Acronyms

ACES	Altus Cumulus Electrification Study
AFRL	Air Force Research Laboratory
ARM	Atmospheric Radiation Measures program
CBP	Bureau of Customs & Border Protection
CIRPAS	Center for Interdisciplinary Remotely Piloted Aircraft Studies
DFRF	Dryden Flight Research Facility
DHS	Department of Homeland Security
DISA	Defense Information Systems Agency
DoD	Department of Defense
DoE	Department of Energy
ERAST	Environmental Research Aircraft and Sensor Technology program
F-H	Flight-hour
FSCM	Flight Service Cost per Mission
FiRE	First Response Experiment
GA-ASI	General Atomics – Aeronautical Systems, Inc.
GSA	General Services Administration
ICE	Bureau of Immigration & Customs Enforcement
HALE	High altitude, long endurance
LCHA	Low cost, high altitude
NASA	National Aeronautics & Space Administration
NCAR	National Center for Atmospheric Research
NOAA	National Oceanic & Atmospheric Administration
ONR	Office of Naval Research
OTH	Over-the-horizon
PI	Principal investigator
ROM	Rough order of magnitude
UAV	Unmanned aerial vehicle

1. Introduction

1.1 Objective

The objective of this study was to identify and evaluate potential business models for private companies to provide NASA with affordable use of unmanned aerial vehicles (UAVs) for science missions.

1.2 Scope

This study focused on providing UAV science flights to NASA over the next five years (2005 – 2009). Only existing fixed wing UAVs were considered (Figure 1-1). Solar-powered UAVs and airships were not considered in the study.

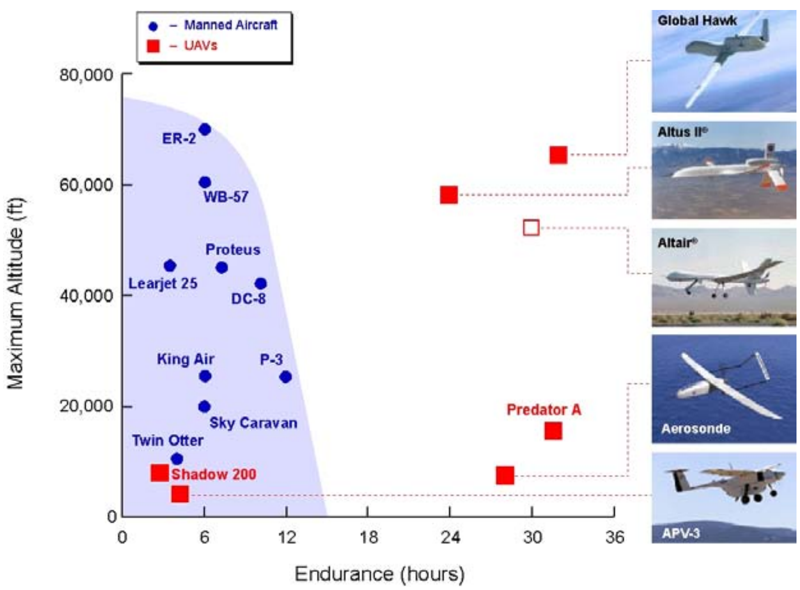

Figure 1-1. Current Manned and Unmanned Aircraft Performance

1.3 Definitions and Concepts

A Business Model defines how a group of organizations provides a service to a customer. A business model is the foundation for a mutually beneficial, long-term relationship between a company and its customers (Magretta, 2002).

For this study, a business model describes how organizations (companies, non-profit organizations, etc.) provide UAV flight services for NASA science missions. Michael Porter's Value Chain (Figure 1-2) is a convenient way to visualize this concept (Porter, 1985). The Value Chain is a series (or chain) of organizations that delivers a product or service to a customer. Value increases from left to right in Figure 1-2. Money flows from right to left.

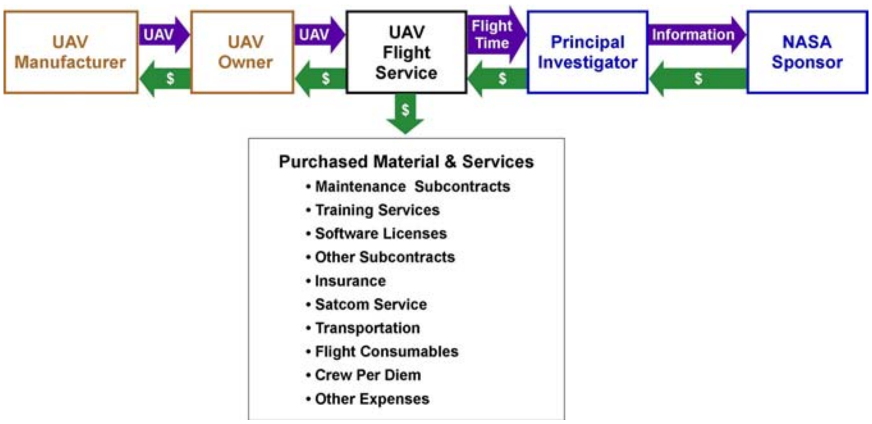

Figure 1-2. UAV Flight Service Value Chain

In this study, NASA is the final customer (at the right end of the Value Chain). A Principal Investigator (PI) is NASA's supplier in the sense that NASA is paying the PI for information. For this study, the information is generated from data collected during a series of UAV flights. Typically, the PI will have a science payload installed on the UAV to collect this data.

The PI might be a NASA employee so the right side of the Business Model is *within* NASA. Alternatively, the PI might be employed by another organization (such as a university). In that case, there is a contractual relationship between the PI and NASA.

For UAV Science Missions, the PI buys *UAV flight services*. There may be other customers (other PIs or other organizations) who also buy these services. The UAV manufacturer is at the beginning of the process.

Between the PI and the UAV manufacturer are the UAV owner and its operator. This study focused on these two parts of the value chain and their relationships with the UAV manufacturer and the PI.

In most cases, the UAV flight service provider, the UAV operator, would prefer to use one type of UAV, or at least have a common set of ground control equipment. If there is only one manufacturer for this class of UAV, it will be in a position to set and maintain high prices.

The functions on the left side of the Business Model can be combined, just as they can on the right side. The UAV manufacturer could also be the owner. The owner could be the operator. One company might manufacture, own, and operate the UAV. To date, this is the most common Business Model used to provide UAVs for NASA science missions.

Flight services and *leasing* are two other terms used in discussions of how best to provide UAVs for NASA science missions. In this study, a flight service provider is a business entity that operates its UAVs for customers, such as NASA PIs. It plans the UAV flight operations, supplies the UAV, and installs and removes the customer's payload. The flight service provider must have the necessary ground equipment and crew to operate and maintain its UAVs.

Leasing is a business transaction where a third party (a leasing company) buys equipment from a manufacturer. The leasing company sells a flight service provider use of the equipment (such as a UAV). The flight service provider takes possession of the UAV and ground equipment, and is responsible for providing the crew and routine maintenance. Aircraft leasing is common among commercial flight services that use manned aircraft. Many commercial airlines lease their aircraft. Tax and other business considerations make leasing financially advantageous for the vehicle operator (the lessee) and profitable for the vehicle owner (the lessor).

For this study, a UAV *mission i*s defined as the time to prepare the UAV, install the payload, verify the installation, ship the UAV and ground equipment to a remote site, conduct flights operations, return the equipment to its home base, and remove the payload (Figure 1-3). In simple terms, a mission is the time the UAV must be *committed* to support a specific set of flights.

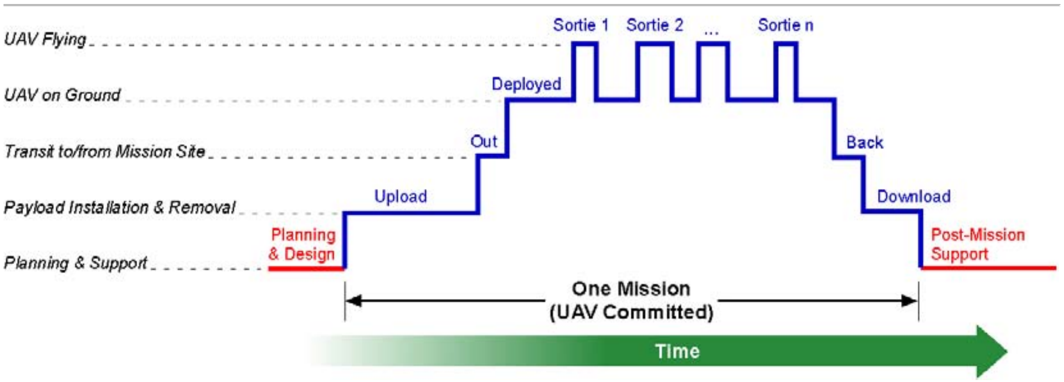

Figure 1-3. Generalized UAV Science Mission

The time to prepare the UAV, install the payload, and verify the installation is called *upload*. The time to remove the payload is download. During flight operations, a *sortie* is one UAV making one flight. Each hour the UAV is in the air is called a *flight-hour* (F-H). The hours a UAV spends actually collecting data can be substantially less than the flight-hours accumulated in one sortie.

For most science experiments, some planning and installation design may be required prior to upload. These are *pre-mission* activities. Similarly, tasks that support the PI (such as assisting with documentation) after the download are called *post-mission* activities.

NASA has commonly reported UAV costs in dollars per flight-hour plus mission peculiar costs. The cost per flight-hour is a marginal cost, reflecting the change in cost with flight time. Mission peculiar costs are non-recurring costs typically incurred during up and download.

In this study, costs are reported as the *Flight Service Cost per Mission (FSCM)*. This is the total price charged for UAV flight services during a science mission. The FSCM is related to the cost per flight-hour and mission peculiar costs by this relationship:

$$\underbrace{FSCM}_{\text{Cost Metric Used in This Study}} = \underbrace{(\text{Cost per Flight-Hour} \times \text{Flight-Hours}) + \text{Mission Peculiar Costs}}_{\text{Cost Metrics Used in Past NASA UAV Science Missions}}$$

1.4 Approach

Moiré began this study by working with Longitude 122 West to review past UAV science missions. This produced a set of cost and schedule information that Moiré used to develop a financial model, called WingsAbout. Alternative business models for providing UAVs for NASA science missions were evaluated using WingsAbout. In parallel, Moiré identified a set of six alternative Business Models based on the NASA UAV experience, a review of other civil and military UAV operations.

Working with Longitude 122 West and NASA, Moiré estimated future demand for UAV flights from NASA and other organizations. This demand was divided into four segments. The high altitude, long endurance (HALE) segment was selected for business model evaluation (this includes the Altus II, Altair[*], and Global Hawk UAVs). Five UAV utilization scenarios were developed to represent the range of possible demand for HALE UAVs.

A baseline case was defined based around what was considered the most likely utilization scenario, UAV (the Altair), and one business case (traditional commercial flight service). Five alternative business models were evaluated for the Baseline Case. Excursions in financial and operational assumptions were evaluated for the Baseline Case. The impact of using the larger, more expensive Global Hawk UAV was also assessed. This report describes the results.

[*] Altus and Altair are registered trademarks of Global Atomics – Aeronautical Systems, Inc.

2. UAV Science Missions

2.1 Aircraft Utilization

Compared to other applications, collecting science data is an inefficient use of modern aircraft. This is an inherent consequence of the scientific process and independent of whether the aircraft is manned or unmanned.

NASA's science aircraft typically fly less than 10 hours for every week they are committed to a science mission (Table 2-1). This reflects the non-flying time needed to install and verify the science payload prior to flight operations and remove the payload afterwards.

Aircraft	*Mission*	*Preparation*[1] *(weeks)*	*Flight Operations (weeks)*	*Recovery*[2] *(weeks)*	*Total Duration (weeks)*	*Flight Time (F-H)*	*F-H per Mission Week*
DC-8[3]	INTEX	6.0	7.0	2.5	15.5	160	10.3
P-3[3]	INTEX	6.0	8.0	1.0	15.0	100	6.7
ER-2[3]	THORPEX	2.0	4.5	2.0	8.5	75	8.8
Altus II[4]	FiRE	3.0	~1	1.0	5.0	~4	~0.8
Altus II[4]	ACES	2.5	4.0	1.0	7.5	38	5.1

Notes: 1. Payload upload 2. Payload download 3. Planned for FY04 4. Actual

Table 2-1. Utilization of Manned and Unmanned Science Aircraft

When the aircraft is deployed with its science payload, flights are dependent on weather conditions, availability of other science instruments, conflicts with other air traffic, communications availability, and payload reliability. *While deployed, science aircraft rarely fly more than 20 hours in a week.*

NASA managers are well aware of this situation. There is little they can do to reduce the calendar time a science aircraft is deployed. The deployment time is driven by science requirements. Improved reliability and planning has increased the hours that *can be* flown during deployment. More science data *could be* collected. This can be valuable for some, but not all, airborne science missions.

NASA has achieved significant gains by using pods (mounted below the aircraft wings or fuselage) or pallets (installed in the fuselage) to decrease the time and cost to install, verify, and remove science payloads from aircraft. Pods are regularly used on the manned ER-2 and Proteus aircraft (Figure 2-1).

a. ER-2 Superpods
b. Proteus Centerline Pod
c. Internal Arrangement of the Proteus Pod

Figure 2-1. Pods Used on Manned Science Aircraft

Science pods are being designed for the manned P-3 and unmanned Altair aircraft. The next step may be to develop payload pallets for aircraft that cannot carry pods under their wings. Standardized pods and pallets may be developed so payloads can be easily carried on different aircraft.

The low number of science flight hours per mission has significant consequences for UAV pricing for science missions. Most NASA managers and PIs focus on marginal cost per flight-hour. This is a useful metric for estimating how UAV costs vary with changes in flight duration. However, most of the cost of UAV flight services comes from mission peculiar costs incurred while the UAV is on the ground. *To date, mission peculiar costs have been the major source of revenue for companies providing UAVs for NASA's science missions*.

2.2 Past UAV Flight Service Costs for Science Missions

NASA, the US Department of Defense (DoD), the US Department of Energy (DoE), and the National Science Foundation (NSF) have funded UAV science missions.

2.2.1 NASA-Funded UAV Science Missions

NASA has funded four UAV science missions since 2001 (Table 2-2). All involved some type of remote sensing. In every case, NASA's PI purchased flight services from the manufacturer of the UAV used for the mission.

Mission	*UAV*	*Location*	*Date*	*Description*
FiRE	Altus II	El Mirage, CA	September 2001	Remote sensing of a wildland fire
ACES	Altus II	Key West, FL	August 2002	Remote sensing of thunderstorms
Coffee Harvest	Pathfinder Plus	Kauai, HI	September 2002	Remote sensing of a coffee plantation
Vineyard	APV-3	San Bernabe, CA	August 2003	Remote sensing of a vineyard

Table 2-2. NASA UAV Science Missions

The Coffee Harvest Optimization mission in 2002 used the solar-powered Pathfinder UAV*. Too much developmental equipment was used to provide useful cost information. The 2003, the Vineyard Project used the small APV-3 UAV (Johnson, 2003). It represents the low end of UAV science missions in terms of cost and performance. It does not reflect how science missions with larger UAVs might be flown.

Longitude 122 West provided cost and schedule data from the First Response Experiment (FiRE) and Altus Cumulus Electrification Study (ACES) proposals that were used in developing WingsAbout mission cost model used in this study.

FiRE was the first UAV science mission that used a state-of-the-art HALE UAV, the Altus II (Ambrosia, 2003). Three weeks were required to prepare the UAV, install the payload, and verify the system. A one-hour data-gathering sortie was flown. This mission was too short to provide useful cost information for this study.

ACES was a more ambitious UAV science mission (Iannotta, 2003; Wegener and Schoenung, 2003). The plan was to fly the Altus II UAV for 128 hours in two deployments. The total proposed UAV flight service cost was $19,433 per flight-hour. Insurance comprised approximately 24% ($4,700) of this cost. Use of the Altus II UAV (essentially the FSCM) constituted 48% of the total mission cost to NASA (Figure 2-2).

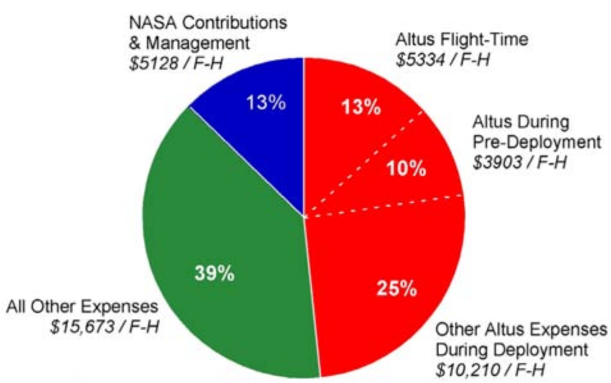

Figure 2-2. Distribution of Proposed Costs for the ACES UAV Science Mission

The Altus II did not fly nearly as much as planned. Although two deployments were planned, the UAV was deployed only once for four weeks. It flew 13 sorties and accumulated 38 flight-hours.

However, ACES had an exceptionally well-prepared proposal. Despite the actual small number of hours flown, it is the best foundation for estimating UAV flight service costs for science missions.

* The Coffee Harvest Mission was proposed and selected through NASA NRA-00-OES-02, “UAV-based Science Demonstration Program.”

2.2.2 DoE UAV ARM

Starting in November 1993, the Sandia National Laboratory started flying UAVs for the Department of Energy's Atmospheric Radiation Measurements (ARM) program (Bolton 2003). By 1999, Gnat-750 and Altus UAVs accumulated 141 hours for the program. However, twice as many hours were flown by manned aircraft (Figure 2-3).

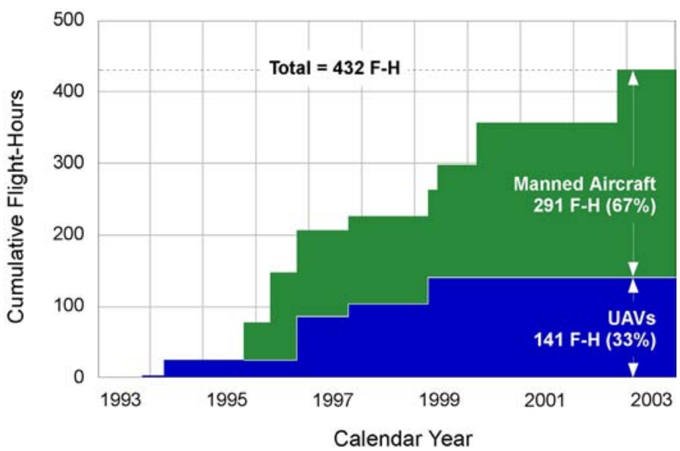

Figure 2-3. Aircraft Utilization during the DoE ARM Program

Despite considerable early enthusiasm for using UAVs to collect science data, the manned Proteus became the primary science platform for the ARM program (Figure 2-4). Unlike older manned aircraft used for most science missions, the Proteus is a state-of-the-art aircraft with relatively low operating costs, attractive performance, and has a configuration designed to carry a large payload pod. Other government agencies are funding Proteus missions.

Manufacturer	Scaled Composites
Propulsion	Two Turbofan Engines
Gross Weight	12,500 lb
Payload Weight	2,200 lb
Altitude	45,000 ft
Airspeed	280 knots
Endurance	7 hours
Range	2,000 nm
First Flight	September 1998
Current Status	One Operational Vehicle

Figure 2-4. Proteus Manned HALE Aircraft

2.2.3 CIRPAS

The Office of Naval Research established the Center for Interdisciplinary Remotely-Piloted Aircraft Studies (CIRPAS) in 1996 to provide UAV flight services to the research, development, test and evaluation communities in and outside the Department of Defense (Bluth, 1996). With growing DoD interest in UAVs, CIRPAS has expanded its role to include military training exercises and operational demonstrations.

The current CIRPAS UAV fleet includes two Predator A UAVs, one Gnat-750 (the predecessor to the Predator), and one Altus I. All were manufactured by General Atomics – Aeronautical Systems, Inc. (GA-ASI) and use a common ground station. CIRPAS flies four or five Predator missions per year accumulating about 200 flight-hours. CIRPAS also flies about one Altus I mission per year accumulating approximately 40 flight-hours. There are no current plans for the Gnat-750.

CIRPAS also flies the manned Pelican (a UAV surrogate) and Twin Otter aircraft. Each of these aircraft flies about 250 hours per year. This means UAVs are responsible for about one third of all CIRPAS flight time. In addition, *CIRPAS is accumulating far more UAV flight experience than NASA.*

UAV costs to CIRPAS are considered proprietary by GA-ASI and were not available for review during this study.

2.3 Homeland Security Demonstrations

The US Coast Guard (USCG)and the Bureau of Immigration & Customs Enforcement (ICE) are part of the Department of Homeland Security (DHS). DHS has shown a growing interest in using UAVs (Blazakis 2004). USCG started small UAV demonstrations in 2002 (O'Donnell and Schaefer, 2003). Since then, ICE and USCG funded two Predator UAV demonstrations (Table 2-3). Both involved long distance deployments, but neither involved a modification to the UAV.

Location	*Customer*	*Date*	*Duration (days)*	*Flight-Hours*	*Total Cost of UAV Flight Service*	*Cost / F-H*
Arizona	ICE	October 2003	17	106	$250,000	$2,358
Alaska	USCG	November 2003	5	128	$700,000	$5,469

Table 2-3. DHS Predator Demonstrations

DHS is now planning two new UAV demonstrations. Hermes UAVs will be evaluated on the Southern US Border (Tiboni 2004). The Coast Guard plans to fly the Altair UAV in Alaska in the summer of 2004*.

* The Altair UAV will also be flown for the Canadian Armed Forces in the Atlantic Littoral Intelligence, Surveillance, Reconnaissance Experiment (ALIX) in August 2004.

2.4 Current NASA UAV Science Initiatives

2.4.1 Aerosonde Flight Services

In late 2003, NASA signed a three-year contract with Aerosonde Pty. Ltd. to provide Aerosonde flight services at Wallops Flight Facility (NASA, 2003). First UAV flights occurred for Wallops Island in February 2004.

This is the closest NASA has come to contracting for UAV flight services. The Aerosonde contact specifies a price of $785 per flight-hour for NASA users. (Williams, 2003).

2.4.2 Altair "Lease"

NASA Dryden Flight Research Facility signed a contract with GA-ASI that provides NASA with 90 days use of the Altair UAV during FY 2004 for a price of $150,000. Although this arrangement is often called a lease, it is not. The contract simply reserves time NASA can hire GA-ASI to fly the UAV. NASA does not take possession of the vehicle. The contract has provisions for GA-ASI to provide flight services with the Altair at additional cost during the 90-day period.

The contract was signed before the Altair flight envelope was verified. By the end of April 2004, the UAV had only flown to 25,000 ft — approximately half its design altitude. Consequently, Altair is not ready for HALE UAV science missions and NASA will not use the 90 days of availability it bought under the agreement for FY 2004.

The Coast Guard plans to use Altair in UAV demonstrations in Alaska during the summer of 2004. It will use part of the time NASA reserved for the Altair and pay NASA approximately $50,000 for the 30 days of Altair use. The Coast Guard is paying GA-ASI $2.5 million for Altair preparation, transportation, and operations. UAV flight insurance is not being purchased for this mission.

2.4.3 Proposed HALE UAV Science Missions

NASA is reviewing seven rough order of magnitude (ROM) prices for possible UAV science missions in FY 2004 (Table 2-4). The ROM prices are for flight services, including UAV operations, as well as non-recurring costs for payload upload and mission planning.

	Mission 1	Mission 2	Mission 3	Mission 4	Mission 5
UAV	Altus II	Altair	Altair	Altair	Altair
Flight Service Cost	$375,000	$200,000	$650,000	$400,000	$150,000
Total Flight-Hours	26	28	72	32	14
Cost per F-H	$14,423	$7,143	$9,028	$12,500	$10,714

Table 2-4. UAV Flight Service ROM Prices for Future Science Missions

2.5 Assessment of Current UAV Flight Service Pricing

Most NASA PIs lack the information and other resources needed to obtain the lowest price for UAV flight services[*]. One problem is that commonly used price metrics mask the true cost of UAV flight services. In addition, PIs are not able to exploit the US government's buying power to obtain the best value for flight services, insurance, and satellite communications.

2.5.1 Price Metrics

There are two problems in assessing UAV FSCM for science missions. First, there is no standard way to estimate and report costs. Requiring all UAV science proposals and reports to use a standard cost template would allow for more useful comparison of cost data in the future. An example of this template is shown in Appendix A.

The second problem is the widespread use of UAV cost per flight-hour to compare UAV operating costs. As explained in Section 2.2.1, cost per flight-hour constitutes only 27% of the total cost of flight service. This metric ignores upload and download expenses, as well as non-recurring operating expenses.

Cost per flight-hour is very sensitive to operating variables. FSCM captures *all* the costs incurred by a UAV provider. It allows the PI and NASA to focus on the *bottom line* and eliminates concern about how the UAV operator allocates expenses.[†]

2.5.2 Flight Operations

NASA PIs have traditionally sought UAV services from manufacturers. However, UAV services are available on the General Services Administration (GSA) schedule. SRA and Battlespace both offer to fly UAVs at competitive prices. All federal agencies can procure UAV flight services at these prices. To date, most customers have been DoD organizations. Having PIs obtain bids from the GSA schedule would create competition for manufacturers' UAV flight services. The result might be lower prices and better service.

2.5.3 Insurance

There is widespread belief that UAV insurance is a major factor in the relatively high cost of UAV science missions. This is a consequence of comparing cost per flight-hour. The ACES UAV insurance costs were 85% of the cost per flight-hour, but only 24% of the total UAV flight service cost.

Even so, reducing the cost of UAV insurance certainly is worthwhile. Currently, insurance for NASA's UAV science missions is bundled in the UAV manufacturer's

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[*] Other weaknesses in having PIs manage UAV science missions were identified by Wegener and Schoenung (2003).

[†] For scientists this may be a useful analogy: Cost per flight-hour is a *derivative* metric that is sensitive to error. Total usage cost is an *integral* metric that is less sensitive to error.

flight service contract. NASA and its PI have little insight into the terms and pricing of this insurance. Some NASA personnel report that 90% of UAV insurance cost is for liability, including the science payload[*]. Others report the amount of insured liability coverage is set by Air Force regulations for flights in the airspace around Edwards AFB (which includes NASA's Dryden Flight Research Facility and GA-ASI's facility in El Mirage).

In any case, two factors contribute to high UAV insurance costs. First, there is no indication that UAV manufacturers obtain competitive insurance bids. In the US, there are at least seven companies underwriting aviation insurance (see Appendix B). Not all may know about the growing need for UAV insurance. Some may be interested in competing for UAV coverage, even though this is a niche market.

The second factor is widespread misperceptions about the reliability of UAVs. To date, NASA has been using developmental UAVs for its science missions. On one hand, this reduces the expenses associated with UAV acquisition (the UAV was paid for in a development program). On the other hand, it significantly increases the cost of insurance.

There are five ways NASA could reduce the cost of UAV insurance for its science missions:

- Use non-developmental UAVs for science missions
- Educate the insurance industry about its UAV science missions to stimulate competition
- Directly buy long term UAV insurance and allow flight services to use it for science missions
- Facilitate formation of an insurance pool to mitigate individual underwriter's risk
- Subsidize UAV insurance

By taking some of these steps, NASA would not only reduce its own science mission costs, but would also remove one of the major obstacles to expanding civil UAV use in the US.

2.5.4 Satellite Communications

Increasing demand for wideband, over-the-horizon communications is almost a certainty. The convergence of improved UAV performance, sensors that generate enormous amounts of data, and the availability of ubiquitous satellite communications (satcom) have generated unprecedented demand by military UAVs. For instance, the Global Hawk can transmit 50 Mb/s of sensor data for more than 24 hours through its satellite link. UAVs used for science missions are following the same path.

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[*] The remaining 10% is presumably for hull insurance, i.e., to repair or replace of the UAV.

Satcom is typically priced on the time and bandwidth used by a transponder on a satellite. The combination of wide bandwidth and long duration makes satcom expensive for long endurance UAVs. Unfortunately, satcom is the only means to transmit wideband data over the Earth's horizon. Most long-range UAV science missions require satcom services. Some UAVs, like Aerosonde, do not require much bandwidth so they can use relatively low cost satcom services (such as Iridium). Larger UAVs (such as Altair) carry more payload, which generates more data. This increases the required satcom bandwidth.

When NASA PIs propose UAV science missions that need satcom, prices are based on buying services on the spot market. More transponder time must be reserved than planned UAV flight-hours because there is some uncertainty when the UAV will fly.

One way to reduce satcom costs is to use existing federal government contracts. Both the GSA and the Defense Information Systems Agency (DISA) have contracts to provide US government agencies with the lowest price for satcom services.

3. US UAV Market

NASA's ability to obtain low cost UAV flight services is affected by UAV market forces that include demand from other customers and how industry responds to that demand.

3.1 Military Programs

The US market for UAVs has always been dominated by DoD spending. Through the 1980s, annual DoD spending for UAVs was less than $200 million, primarily for research and development (Figure 3-1). Annual spending increased in the 1990s, but only once exceeded $500 million (in FY 1996). In FY 2002, DoD spending on UAVs started to increase rapidly. By FY2004, annual spending is expected to be approximately $1,340 million. FY2005 military spending for UAVs may be 50% higher.

Military spending shifted from primarily research and develop to a mix of production *and* expanded research and development. In the President's FY 2005 Budget Request, UAV procurement comprises 31% of DoD's $2 billion UAV budget. Ten years ago, over 98% of DoD spending for UAVs involved research and development.

Over the past decade (FY1994 – FY2003), NASA spent approximately $100 million on UAVs, primarily to develop a new generation of low cost vehicles. Over the same period, DoD spent $4.9 billion on UAVs. That is, NASA spending comprised about 2% of US government spending on UAVs. *In FY 2005, NASA's UAV budget may be less than 1% of the DoD UAV budget*.

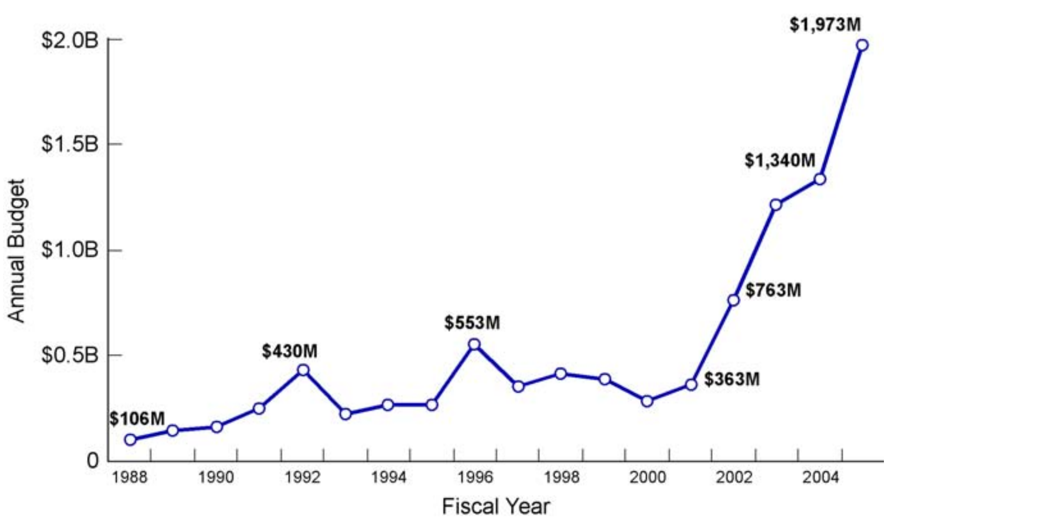

Figure 3-1. Annual DoD Budget for UAVs

DoD is also developing a new generation of unmanned vehicles. One may be an unmanned version of the Gulfstream G550 business jet (Fulghum, 2003a) with significantly greater payload capacity than the Global Hawk (but flying at a lower altitude).

If successful, military high altitude airships could evolve into airborne science platforms. Lockheed Martin is under contract to develop the solar-powered High Altitude Airship (Wilson, 2004). If successful, this vehicle will carry three times the payload of the Global Hawk for month-long missions at the same altitude. The Ascender program is developing an innovative low cost airship that can carry small payloads to higher altitudes (Boyle, 2004)

3.2 Homeland Security Programs

The Department of Homeland Security is showing increasing interest in using UAVs for maritime and border surveillance (Blazakis, 2004; Tiboni, 2004). Within one or two years, DHS may be spending more on UAVs than NASA.

3.3 Private Sector Demand for UAVs

So far, the combination of regulatory constraints and high costs has limited private sector demand for UAVs. This may change within five years because of the convergence of regulatory reform (facilitated by the Access 5 initiative) and DoD interest in fielding large numbers of low cost UAVs. Until then, NASA, DoD, and DHS will form the customer base in the US UAV market.

3.4 Industrial Base

The critical consequence of NASA's diminishing share of the US UAV market is that it cannot attract companies to satisfy its UAV needs. The ERAST program started in 1993 with four small companies: AeroVironment, Aurora Flight Sciences, GA-ASI, and Scaled Composites. AeroVironment and Aurora focused primarily on developing UAVs for non-military applications. At that time, none of the major US prime contractors showed much interest in building the UAV business, so these four relatively small companies comprised much of the US UAV industrial base for UAV development and manufacturing.

Within the past 10 years, the US UAV industrial base experienced a transformation. The large aerospace/defense prime contractors consolidated. Those that remained responded to DoD's interest in UAVs. Today, every prime contractor is involved in at least one major DoD UAV program (Rockwell, 2003). AeroVironment has emerged as a major supplier of small military UAVs. Aurora Flight Sciences is both a military UAV subcontractor and a successful developer of small, innovative military and homeland security UAVs.

Scaled Composites has withdrawn from the UAV market. Ironically, it now offers flight services with its manned Proteus aircraft — which has displaced UAVs in some science missions (see Section 2.2.2).

GA-ASI is the only company now supporting NASA's UAV science missions.

During the past decade, small long endurance UAVs have gained broad acceptance among military and civil customers. Aerosonde and Insitu now provide these types of UAVs to a wide range of US and foreign customers (Fulghum, 2003b; Ramsey, 2004). The companies offer innovative vehicle leases and flight services (NASA, 2003 and Kaufman, 2004).

3.5 Assessment

NASA is in a weak position as a customer in the US UAV market. Not only is it spending far less than DoD, but the UAV industry is also confused about what NASA wants.

Most NASA publicity is generated by UAV development programs. This focuses industry's attention on working with NASA to develop new vehicles and technologies, instead of improving UAV reliability and utility needed for science missions. Focusing attention on UAV development has also created a public perception that NASA UAV programs have high risk. The well-publicized ERAST UAV accidents have reinforced this perception, particularly in the investment community. This may also contribute to the high insurance costs charged for UAV flights.

The low and mid altitude market segments have viable flight services providers. Aerosonde's NASA contract provides PIs with relatively low cost UAV flights, albeit with a small payload capability. CIRPAS offers a UAV flight services in the mid altitude segment. It has grown to be a major US government provider of UAV flight services to military and civil government customers.

GA-ASI is positioned as the only source for UAVs in the mid and high altitude segments. It is unlikely they will support any attempts to attract other companies to provide HALE UAV flight services.

4. Projected NASA Demand

NASA requirements for UAVs to perform science missions were estimated from projections developed for the ERAST program, responses to the UAV Science NRA in 2000, and Moiré UAV market assessments.

4.1 ERAST Studies

In 1999, the ERAST program identified three potential sources of demand for low cost, high altitude (LCHA) UAVs (Mirada, 1999)[*]. One application was *environmental science* including atmospheric and oceanographic research. This essentially reflects the requirements of NASA's UAV science program and other civil science agencies.

Another application was *environmental monitoring and early warning*. This included monitoring the weather in remote oceans areas and searching for hot spots in remote forests.

The Aerosonde has been used to gather weather data over the ocean (Holland, 2003). ERAST explored using long range LCHA UAVs, such as the Altus II and Global Hawk, to gather data to improve prediction of tropical cyclone formation, growth, and trajectory (Wegener, 1998).

Early warning of wildfires was identified as another high payoff application for LCHA UAVs. Small hot spots can be detected from a UAV. Fire managers can quickly respond to extinguish the fire before it gets out of control. The FiRE mission was the first step in developing this capability.

The ERAST assessment also found that *telecommunications* could be a significant LCHA application. UAVs were envisioned as communications relay platforms filling gaps in coverage (such as during disaster recovery operations) or as a supplement to satellite communications networks. This application failed to emerge because the current generation UAVs are too expensive and lack the reliability to compete with alternative communications platforms.

The 1999 ERAST assessment identified a range of UAV performance that could satisfy the anticipated requirements for these applications (Figure 4-1). The Altair and Global Hawk can fly at the altitude and endurance needed for 80% of the projected applications.

Five years later, environment science, and environmental monitoring and early warning, are still driving requirements for UAV science missions. Both these applications are notable because:

- They can yield significant economic benefit
- UAVs have distinct advantages over manned aircraft and satellites

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[*] LCHA and HALE UAVs have approximately the same performance.

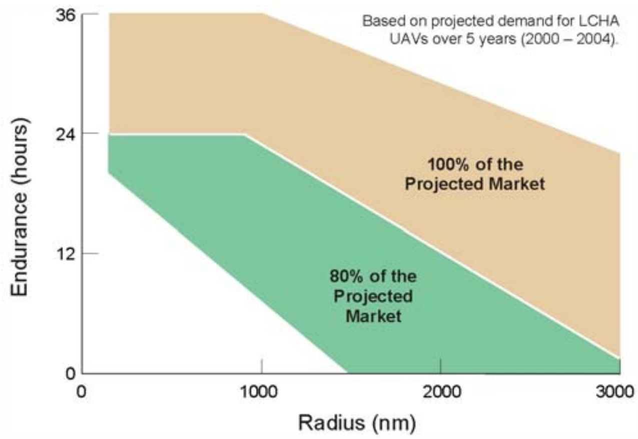

Figure 4-1. ERAST Projection of UAV Performance Requirements

However, today's UAVs are not ready to routinely perform these missions. UAVs must have reliable "high end" UAV performance (long range and endurance). In addition, affordable over-the-horizon (OTH) communications is needed.

4.2 NRA Responses

In 2000, NASA's Office of Earth Science released NASA Research Announcement (NRA) 00-OES-02 for a UAV Science Demonstration Program. NASA received 45 responses that provide a comprehensive picture of demand for UAV science missions.

Longitude 122 West provided the following summary of UAV performance requirements in the responses:

- 33% proposed using a HALE UAV with performance comparable to the Altus II
- 53% required a "long endurance" UAV
- 18% required a UAV that could fly above 45,000 ft

From a science perspective, the responses included these areas:

- 47% involved atmospheric chemistry or physics
- 18% involved meteorology
- 18% involved oceanography

4.3 UAV Market for Science Missions

UAV requirements for science missions can be divided into four segments (Figure 4-2) in terms of endurance and altitude. The manned aircraft segment encompasses performance available with manned aircraft. UAVs must offer *lower cost or improved safety* to compete in this segment.

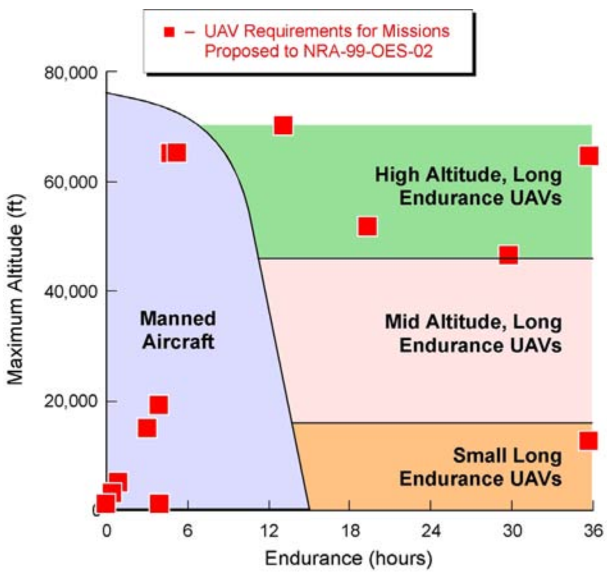

Figure 4-2. Altitude and Endurance of Aircraft Used in Science Missions

There are three segments where UAVs have no direct competition. All are defined by endurance greater than manned aircraft flying at the same altitude. Below 15,000 ft is a segment for small, long endurance UAVs, such as the Aerosonde. This segment is characterized by payload requirements less than 20 lb.

Between 15,000 ft and 45,000 ft is a mid altitude segment that includes the military Predator UAV. Payload requirements range from 10 to 1000 lb in this segment. None of the NRA responses were in this segment, even though several reliable UAVs can provide this capability.

Above 45,000 ft is the HALE segment that includes Altus II, Altair, and Global Hawk. This segment is characterized by payload requirements of 200 – 2000 lb.

A concern in this analysis is that this segmentation may reflect science mission requirements biased by scientists' perception of UAV availability. For instance, a valid requirement for a small payload in the HALE segment would not be proposed. Identifying these atypical UAV science requirements was outside the scope of this study.

There may also be institutional bias in the UAV science requirements proposed to NASA. *No NRA responses called for UAVs in precisely the mid altitude segment that CIRPAS routinely flies its UAVs.*

4.4 Focus on HALE UAVs

Review of the demand in the four UAV science mission segments found that *the HALE segment is the only viable candidate for NASA transition to UAV flight services*. Aerosonde already provides flight services for small, long endurance UAVs. CIRPAS already provides UAV flight services for mid altitude, long endurance missions. Starting a new UAV flight service in the manned aircraft segment would be very difficult (Papadales, 2003).

Within the HALE segment, there are three UAVs that can be used as science platforms: the Altus II, Altair, and Global Hawk (Figure 4-3). As explained in Section 2.4.2, the Altair is still in flight-testing and is not quite ready for HALE science missions.

The Altus II is an older UAV and is not a viable candidate for future flight services. Therefore, the Altair and Global Hawk were the two UAVs evaluated in this study.

	 **Altus II**	 **Altair**	 **Global Hawk**
Manufacturer	GA-ASI	GA-ASI	Northrop Grumman
Propulsion	• Pusher Propeller • Turbocharged Piston Engine	• Pusher Propeller • Turboprop Engine	• Turbofan Engine
Gross Weight (lb)	2,100	7,000	25,600
Payload Weight (lb)	330	750	2,000
Wing Span (ft)	55	86	116
Length (ft)	22	36	44
Altitude (ft)	58,000	52,000	65,000
Airspeed (knots)	110	150	340
Endurance (hours)	24	30+	32
Range (nm)	2,600	4,500	8,900
First Flight	May 1996	June 2003	Feb 1998
Current Status	One Operational Vehicle[*]	One Vehicle in Flight Test	In Production

Figure 4-3. HALE UAVs Available for NASA Science Missions

[*] The Altus I UAV (also called the Altus ST) is operated by CIRPAS. It cannot operate at high altitude.

4.5 Projected HALE UAV Utilization

Based on the available information about HALE UAV demand from the science community and other civil users, five scenarios for UAV utilization were developed (Table 4-1). Each spanned five years. The primary variable was how many missions were sold to all customers and what share was sold to NASA.

Utilization Scenario	Total UAV Missions Sold	NASA Share	UAV Missions Sold to NASA	UAV Sorties Sold to NASA	UAV Flight-Hours Sold to NASA
Mid-50 (Baseline)	50	50%	25	184	3,500
Mid-100	50	100%	50	368	7,000
Low-100	25	100%	25	184	3,500
High-50	100	50%	50	368	7,000
High-100	100	100%	100	736	14,000

Table 4-1. 5-Year UAV Utilization Scenarios

The Mid-50 scenario was used in the Baseline Case described in Section 7. In this scenario, NASA purchases 25 HALE UAV missions over five years. Another 25 missions are sold to other customers (so NASA's share is 50%).

Over the five years, the missions per year increase, as do the number of sorties per mission and the flight-hours per sortie. This reflects the anticipated improvements in efficiency of flight operations, as well as increased demand over time. The cumulative increase in UAV utilization is shown in Figure 4-4 for the baseline case. The alternate scenarios also have the progressive increase in UAV utilization. Each reflects different numbers of missions bought by NASA and other customers.

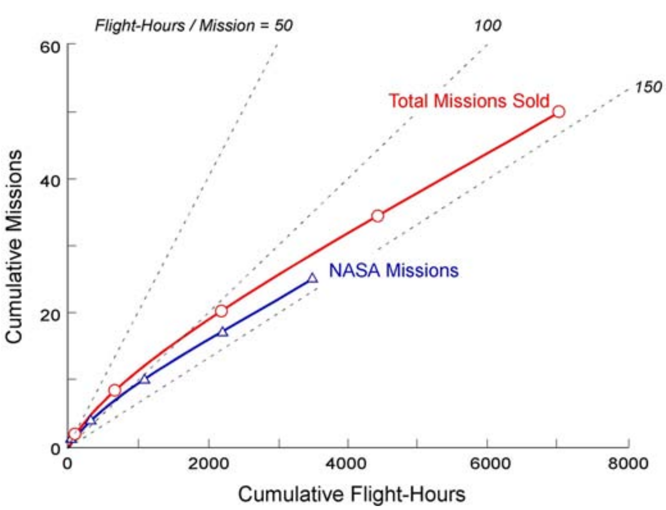

Figure 4-4. Increasing UAV Utilization in the Mid-50 Scenario

5. Alternative Business Models

Identifying alternative business models for UAV science missions revolves around two distinct choices: who owns the UAV and who operates it. There are three practical alternatives for each, creating nine distinct business models, as shown in Figure 5-1. However, a ground rule for this study is that NASA cannot be the UAV operator. This leaves six possible business models as indicated in green in Figure 5-1. All were evaluated in this study.

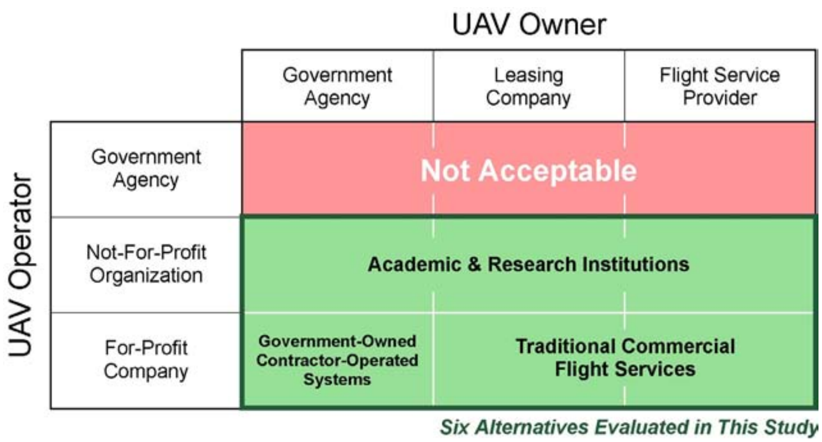

Figure 5-1. Alternative Business Models for UAV Science Missions

There is also a strong desire among senior NASA managers to avoid having NASA own UAVs that are used for science missions. This would eliminate another two alternative business models. However, the high cost of UAV acquisition may make other business models impractical. There is also the possibility that another government agency might own the UAVs. Therefore, alternative business models with government-owned UAVs were evaluated in this study.

6. Financial Modeling

To evaluate the alternative business models, Moiré developed the Excel-based WingsAbout model (Moiré, 2004). The model estimates FSCMs for the six business models for a UAV utilization scenario and a set of financial assumptions.

WingsAbout was developed to compare different business models. Expenses are based on relatively simple relationships developed from the limited UAV cost data available. Some expenses are not included because they depend on specific business details that cannot be estimated with confidence. For instance, the model does not estimate business start-up expenses that might be incurred during the first year or two of operation.

With so little UAV cost data as a foundation, WingsAbout projections for UAV flight service prices may be optimistic. That is, the projected prices may be lower than those derived from more rigorous analysis.

The model assumes a distinct business unit (a for-profit company or non-profit organization) provides UAV flight services to a group of customers.

The model calculates the total annual expenses over five years to satisfy the specified utilization scenario. WingsAbout projects annual income statements for each of the six alternative business models. Flight service prices are calculated by dividing the annual revenue by the number of missions sold[*].

WingsAbout only estimates the price for *UAV flight services*. There are many other costs that must be included in an estimate of total mission cost to NASA (Table 6-1).

To facilitate cost estimation, WingsAbout assumes one representative mission is repeated as many times as needed to satisfy the utilization scenario. Several of the input variables describe this representative mission, including transportation to and from the mission site. The mission expenses include costs to maintain the flight operations crew at the mission site.

UAV costs are represented as an initial acquisition cost; an annual maintenance and support cost (that includes annual outside maintenance contracts, etc.); and operating costs at the mission site. The number of people required for maintenance and operations are independent variables. Staff for pre-mission, upload, download, post-mission activities, as well as General and Administrative functions are determined automatically.

Satellite communications expenses are an independent variable. Annual insurance premiums are determined automatically from the cost of equipment covered and number of missions — not the projected annual flight-hours.

In cases where the UAV and ground equipment are owned by the operator, WingsAbout provides the flexibility to vary financing and depreciation options.

[*] From a government customer's perspective, WingsAbout prices are equivalent to those allowed under cost reimbursement contracts.

Price Elements Included in the UAV-Serve Price Model	*Other Mission Costs Incurred by NASA*
• UAV Acquisition • Ground Equipment Acquisition • Transit to and from the Mission Site • UAV Operating Consumables • Support Costs at the Mission Site • Satellite Communications • Insurance • Maintenance & Support Subcontracts • Payload Installation Design, Implementation, & Removal • Pre-Mission Verification • Mission Planning Support • Obtaining Regulatory Approvals • Labor & Fringe Benefits • Other G&A (rent, utilities, etc.) • Federal Taxes • Profit	• Payload Development & Acquisition • Payload Modification & Verification • Data Reduction & Storage Equipment • Science Team Labor • Science Team & Equipment Transit to and from the Mission Site • Science Team Support at the Mission Site • Liaison With UAV Flight Service • Other (Manned) Aircraft Operations • Use of Other Facilities • Mission Planning • Data Analysis • Documentation • Outreach • NASA Management & Engineering • Other Expenses

Table 6-1. Comparison of WingsAbout and NASA UAV Science Mission Costs

7. Baseline Case

The Baseline Case is a commercial flight service company that flies the *Altair UAV*. The company buys the UAV with traditional financing. UAVs and ground equipment* are purchased to meet the demand in the Mid-50 utilization scenario. The company sells 50 UAV missions over five years. These missions include 368 sorties with 7,000 flight-hours. NASA buys half these missions (50% share).

The UAV acquisition price is estimated using DoD budgets for the Predator B UAV. The Altair is a derivative of the Predator B. The FY 2005 estimates of Predator B costs are shown in Appendix C. For the baseline case, the Altair unit price was assumed to be $8 million. This is $750,000 lower than the Predator B unit price, reflecting an assumption that some military subsystems would not be installed.

Ground equipment is priced as a set that includes a ground control station, communications terminal, and deployment equipment for the UAV. Based on the Predator prices, the Altair ground equipment unit price was set at $6 million; this is $3.4 million less than comparable Predator B prices.

UAV and ground equipment prices are constant over the five years. A five-year depreciation period is used to calculate depreciation expenses for all UAV-related equipment.

Insurance costs are based on providing $10 million in liability coverage plus replacement value of the UAV-related assets. The annual insurance expense is the sum of:

- 2% of the replacement value of the UAV inventory
- 0.5% of the replacement value of the ground equipment inventory
- $30,000 per mission

Satcom is assumed to be needed for *one half of the missions sold*. Satcom hours reserved are *twice the planned flight-hours* (to account for uncertainties in flight times). The average satcom cost for all missions is $420 per hour. This is reduced 2% per year with no adjustment for inflation.

The average employee salary (with fringe benefits) is $65,000 in Year 1. General and Administrative (G&A) expenses are $55,000 per employee. These expenses include rent, utilities, training, etc. Salaries and G&A increase with inflation. The baseline case uses a 2% annual inflation rate.

The company has a 5% profit margin, which is constant over the five years.

A complete list of the assumptions in the Baseline Case is in Appendix D.

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* Ground equipment includes the ground control station and other non-flying support equipment.

Table 7-1 shows how UAV flight services would expand over five years. During this period the number of mission sold per year increased by a factor of eight, sorties per mission double, and flight-hours per mission almost triple.

	Year 1	*Year 2*	*Year 3*	*Year 4*	*Year 5*
Missions Sold to NASA	1	3	6	7	8
NASA Share	50%	50%	50%	50%	50%
Total Missions Sold	2	6	12	14	16
Calendar Weeks / Mission	16	12	10	8	8
Total Mission-Weeks	32	72	120	112	128
Flight Operations Weeks / Mission	4	4	4	4	4
Total Flight Operations Weeks	8	24	48	56	64
Sorties / Mission	4	6	7	8	8
Average Flight-Hours/Sortie	14	16	18	20	20
Total Sorties	8	36	84	112	128
Flight-Hours / Mission	56	96	126	160	160
Total Flight-Hours	112	576	1,512	2,240	2,560
Cumulative Flight-Hours	112	688	2,200	4,440	7,000
People Deployed / Mission	6	4	4	4	4
Downtime Weeks / UAV	20	16	12	15	9

Table 7-1. Equipment Utilization and Deployed Crew for the Baseline Case

One constant across the five years is the weeks of flight operations per missions, that is the time deployed (Figure 7-1). This reflects the assumption that the time deployed is driven by the science mission, not by UAV availability. However, both up and download times decrease over the five years. The total mission duration drops from 16 weeks in Year 1 to eight weeks in Year 4.

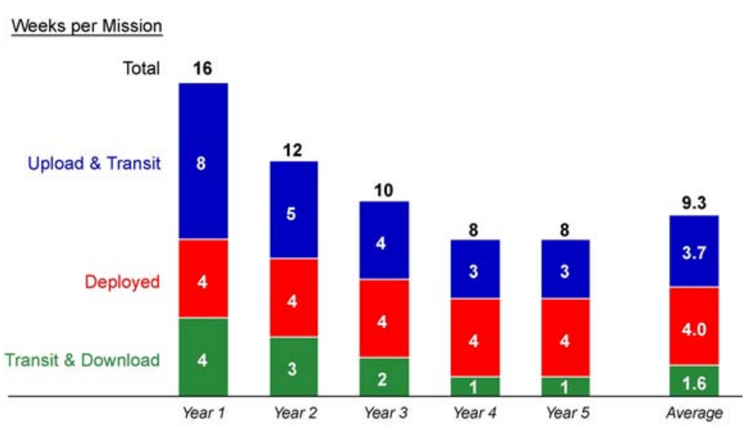


Figure 7-1. Assumed Reductions in Mission Duration

7.1 Estimated Costs

In Year 1, NASA's first mission would cost $3.5 million (Figure 7-2). This would drop 62% over the five years. The average FSCM would be $1.64 million. Depreciation and interest expenses constitute 52% of this cost.

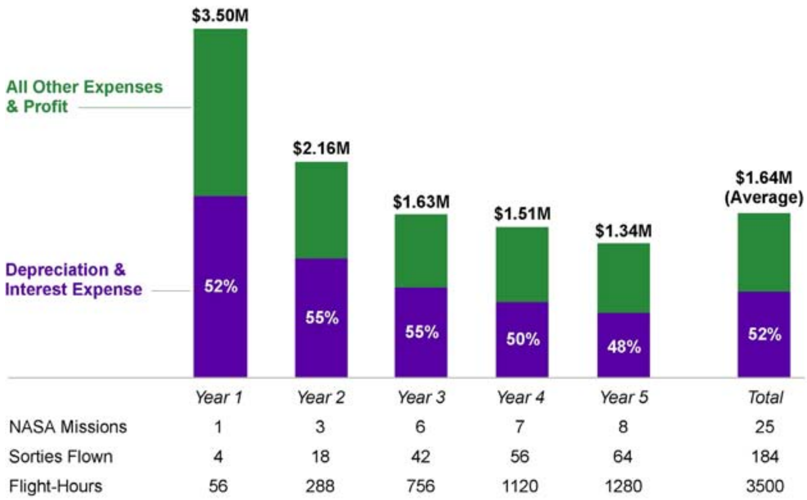


Figure 7-2. Estimated NASA Flight Service Cost per Mission for the Baseline Case

Since the flight-hours per mission increase over time, the cost per flight-hour drops faster than the FSCM (Figure 7-3). In Year 1, the UAV cost per flight-hour is $62,400. This falls by 64% in one year and by 87% by Year 5.

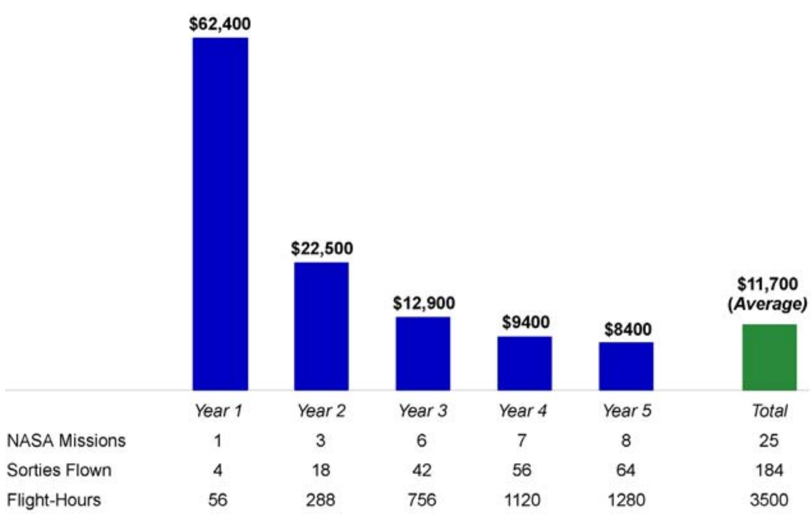


Figure 7-3. Estimated NASA Flight Service Cost per Flight-Hour for the Baseline Case

The company's income statement shows how quickly it saturates the HALE UAV market (Table 7-2). Over the first three years, revenue grows on average at 67% per year. From Year 3 to Year 5, the annual rate of growth slows to about 5%. If the company wants to continue to grow, it would have to find other markets for its UAV services a few years after it starts business.

	Year 1	Year 2	Year 3	Year 4	Year 5
Missions Sold	2	6	12	14	16
Average Price per Mission ($)	3,496,608	2,159,192	1,630,696	1,506,453	1,338,840
Total Revenue ($)	6,993,216	12,955,151	19,568,353	21,090,347	21,421,433
Expenses ($)					
Direct Mission Costs (no labor)	443,840	1,190,170	2,381,486	2,952,707	3,299,476
Salaries, Wages, and Benefits	1,170,000	1,657,500	2,231,658	2,759,141	2,814,324
General and Administrative	990,000	1,402,500	1,888,326	2,334,658	2,381,351
Insurance	250,000	563,600	944,544	1,015,707	1,089,567
Depreciation	2,800,000	5,600,000	8,400,000	8,400,000	8,400,000
Interest Expense	840,000	1,616,271	2,324,989	2,122,101	1,907,040
Total Expenses	6,493,840	12,030,041	18,171,003	19,584,313	19,891,757
Income Before Taxes ($)	499,376	925,110	1,397,350	1,506,034	1,529,676
Taxes ($)	150,008	277,894	419,750	452,398	459,500
Income After Taxes ($)	349,369	647,216	977,600	1,053,636	1,070,177
Profit Margin	*5%*	*5%*	*5%*	*5%*	*5%*

Table 7-2. Projected UAV Flight Service Company Income Statement

For the Baseline Case, the flight services company requires only three UAVs during the five-year period. During that time, it can generate about $7 million per UAV per year (Table 7-3).

Employment grows from 18 to 40 people. After the first year, annual revenue per employee is between $500,000 and $600,000. By Year 3, revenue per employee is declining, suggesting operating efficiency is not improving.

	Year 1	*Year 2*	*Year 3*	*Year 4*	*Year 5*
Equipment					
UAVs	1	2	3	3	3
Ground Stations	1	2	3	3	3
Revenue Per UAV ($)	6,993,216	6,477,575	6,522,784	7,030,116	7,140,478
Staff (eq. full-time positions)					
Flight Operations and Technicians	10	14	20	24	24
Engineering and Marketing	3	4	5	6	6
Management	1	2	2	3	3
Administrative	4	5	6	7	7
Total	18	25	33	40	40
Revenue Per Employee ($)	388,512	518,206	592,980	527,259	535,536

Table 7-3. Annual Revenue per UAV and Employee

7.2 Comparison with Actual Costs

Results from the WingsAbout analysis of the Baseline Case cannot be validated with the limited UAV cost and operations data available. Nonetheless, comparison with existing UAV costs can be illuminating.

To make this comparison, the marginal cost per flight-hour was calculated for the Baseline Case. This is comparable to the Altus II costs quoted for the ACES and FiRE missions. The Altus II cost per flight-hour is approximately $5,320 or 5% higher than the first year cost projected by WingsAbout (Table 7-4). The average over five years is 63% lower.

	Study Results (Altair – Baseline Case)		Altus II (Actual)
	Year 1	5-Year Average	
Without Insurance	$ 2,225	$ 1,055	$ 530
Insurance	$ 2,823	$ 926	$ 4,790
Total	$ 5,048	$ 1,981	$ 5,320
Insurance / Total Price	*56%*	*47%*	*90%*

Table 7-4. Comparison of UAV Marginal Costs per Flight-Hour

A similar calculation was done to compare WingsAbout results with the existing 90-day NASA lease for the Altair UAV (Table 7-5). The WingsAbout Costs are seven times higher because of depreciation and interest expenses. If these are omitted, the WingsAbout costs are approximately 20% less than the current NASA lease.

	Study Results (Altair – Baseline Case)		Altair (Actual)
	Year 1	5-Year Average	
Without Depreciation & Interest	$ 120,000	$ 124,000	$ 150,000
Depreciation & Interest	$ 957,000	$ 958,000	N/A
Total	$ 1,077,000	$ 1,080,000	$ 150,000
Depreciation & Interest / Total Price	*89%*	*89%*	*N/A*

Table 7-5. Comparison of UAV Availability Costs for 90 Days

8. Variations of the Baseline Case

Analysis of variations of the Baseline Case included the alternative business models, as well as a wide range of operational and financial variables. This provided some insight into the robustness of the Baseline Case and the alternative business models.

8.1 Mission

8.1.1 Flight-Hours per Sortie

UAV FSCM is not very sensitive to the number of hours flown. Figure 8-1 shows how the average UAV FSCM varies with changes in the average number of flight-hours per sortie, for a fixed number of sorties. The Baseline Case has 50 missions with 368 sorties and 7,000 flight-hours. The UAVs fly approximately 19 flight-hours per sortie. Decreasing the flight-hours per sortie by 50% reduces the average UAV mission cost by 2%, but increases the cost per flight-hour by 95%. A 50% increase in flight-hours per sortie results in a 2% increase in FSCM and a 32% reduction in cost per flight-hour.

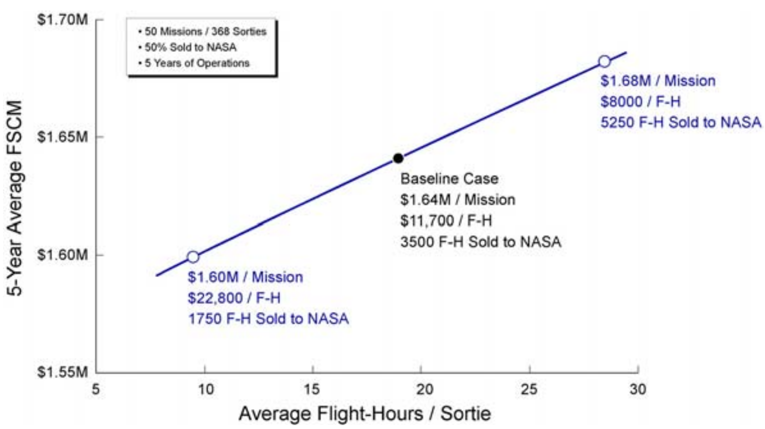


Figure 8-1. Impact of Flight-Hours per Sortie on FSCM

8.1.2 NASA Share of Missions Sold

NASA's FSCM is sensitive to its share of the total missions sold. In the Baseline Case, NASA buys 3,500 UAV flight-hours over 25 missions. This is one half of the total missions sold. If NASA is the only customer, its average UAV FSCM increases 30%, from $1.64 million to $2.14 million (Figure 8-2).

Increasing the number of missions (and flight-hours), reduces the FSCM. If the UAV flight service can sell 50% more missions and NASA's share remains 50%, average UAV FSCM will decline 7% to $1.53 million.

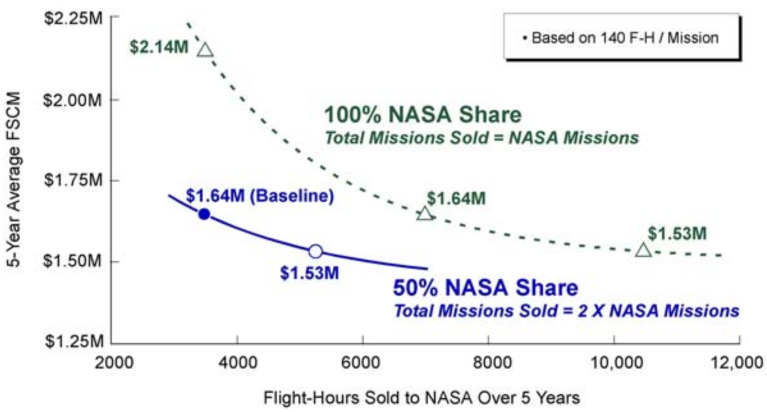


Figure 8-2. Impact of Total Flight-Hours and NASA Share on FSCM

8.1.3 Scheduling

FSCM is very sensitive to mission scheduling. By shifting one mission from Year 2 to Year 1, the FSCM in Year 1 falls from $3.50 million to $2.77 million. If the first two missions were sold at $3.50 million each, the extra mission would cost $1.32 million.

8.1.4 Continuous UAV Coverage

There will probably be cases where a mission requires UAVs to continuously fly in an area for longer than one UAV's endurance. This will require deploying two UAVs and crews on one mission. The increase in flight-hours depends on how much time a UAV uses to fly to and from the area being continuously covered. Deploying a second UAV and crew, without increasing the total mission flight-hours, increases the average flight service cost by more than 90% (Figure 8-3).

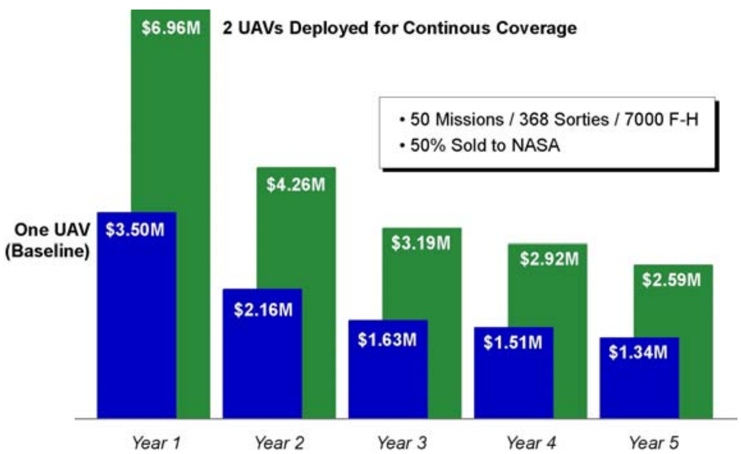


Figure 8-3. Increase in FSCM with 2 UAVs Deployed for Continuous Coverage

8.2 Equipment Finances

8.2.1 Acquisition Cost

Flight service costs are relatively sensitive to UAV and ground equipment acquisition cost. Averaged over five years, a $1 million change in acquisition price results in a $74,000 change in FSCM (Figure 8-4). Mission cost in Year 1 is more sensitive. A $1 million change in acquisition cost results in a $158,000 change in FSCM.

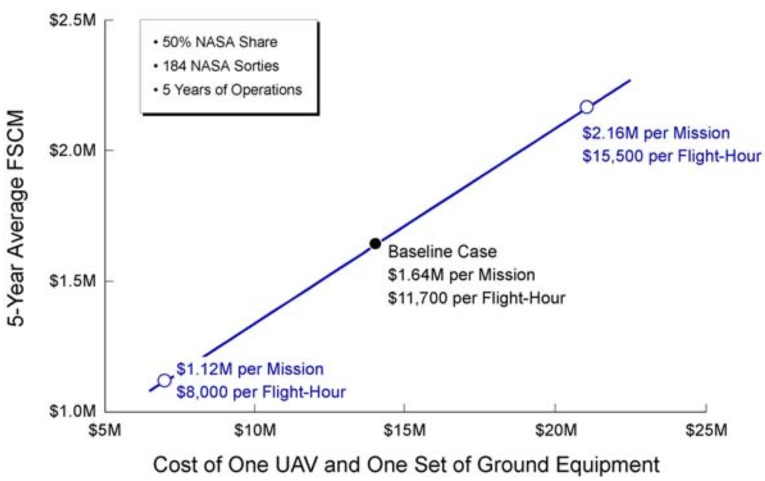
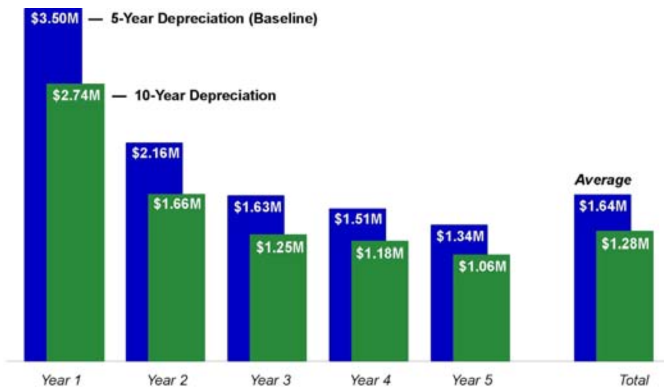


Figure 8-4. Impact of Equipment Acquisition Cost on FSCM

8.2.2 Depreciation

The average FSCM is very sensitive to the period over which the UAV and ground equipment are depreciated (Figure 8-5). By increasing the depreciation period from five to ten years, the average FSCM decreases 22%. In Year 1, the FSCM declines 24%, from $3.50 million to $2.74 million.



	Year 1	Year 2	Year 3	Year 4	Year 5	Total
NASA Missions	1	3	6	7	8	25
Sorties Flown	4	18	42	56	64	184
Flight-Hours	56	288	756	1120	1280	3500

Figure 8-5. Effect of Depreciation Period on FSCM

Assuming NASA is paying for UAV flight services under a cost reimbursement contract, the lowest price results from the flight service provider using as long a depreciation period as possible. However, a for-profit flight service may prefer to use as short a depreciation period as allowed under the tax code to minimize its tax liability. This is why most companies prefer to depreciate equipment as fast as permitted under the tax code.

Consequently, if NASA uses a cost reimbursement contract for UAV flight services, even for the first few years, it should review how depreciation expenses are being calculated.

8.2.3 Leasing

Average FSCM could change if the flight service provider chose to lease its UAV and ground equipment from a commercial leasing company (Figure 8-6). If a five-year lease were negotiated, the average FSCM would decline 16%. If NASA (and other customers) can only make short-term commitments to buy UAV flight services, the flight service provider might have to sign a one-year lease. The average FSCM would increase 19%.

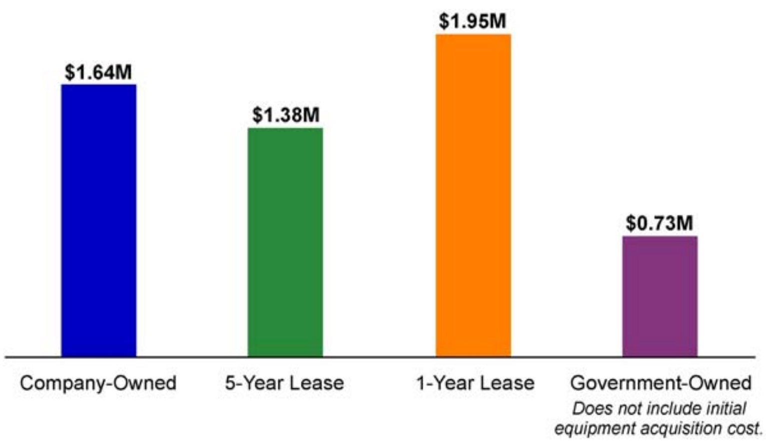


Figure 8-6. Effect of Equipment Leasing Terms and Government Ownership on FSCM

8.2.4 Government Ownership

Although not preferable to NASA, it could *purchase* UAVs and ground equipment that are then operated by a flight service company. Of course, NASA would have to buy the needed UAVs and ground equipment *before* they can be used by the flight service. Proper timing of vehicle and ground equipment acquisition would be a challenge.

If the equipment acquisition costs are disregarded, the average FSCM is 55% lower (Figure 8-6). This reflects the significant contribution of UAV acquisition cost in average FSCM for the Baseline Case.

NASA might buy UAVs and ground equipment *if it were the only user*. In this case, the total five-year cost to NASA (for acquisition and flight services) is approximately $51.1 million for 25 missions (Figure 8-7). The total cost of flight services with company-owned equipment is $53.5 million. The five-year cost of the Baseline Case (where the flight service sells 25 missions to NASA and 25 missions to other customers) is $41.0 million.

This shows that even if NASA is the only user, it is probably preferable to have the flight service own the UAVs and ground equipment. That way, the company and NASA would be strongly motivated to find other customers — and NASA incurs a minimal cost for that possibility.

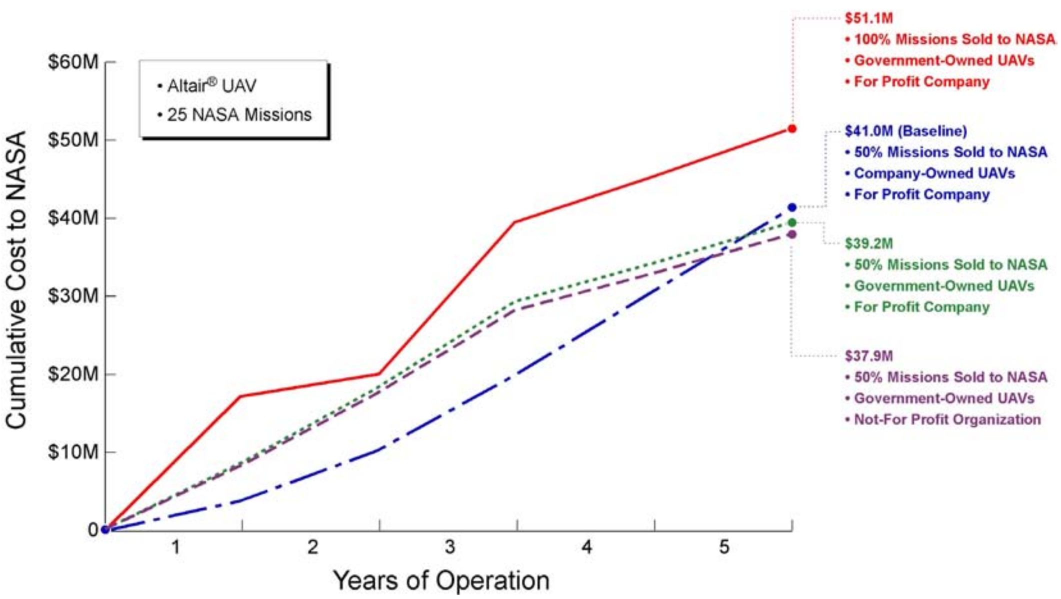


Figure 8-7. Cumulative UAV Flight Services Cost to NASA

8.3 Expenses and Profit Margin

There is considerable uncertainty in the flight service's estimated expenses. The cost of UAV and ground equipment make up such a large part of the cost of UAV flight services that even 100% increases in most other costs have little impact (Figure 8-8 on the following). One exception is labor and G&A costs. In this case, doubling these costs results in a 26% increase in UAV FSCM.

Doubling the profit margin (to 10%) results in a 7% increase in FSCM. If the profit margin were zero (such as for non-profit flight service), the flight service cost would be 7% lower. However, a non-profit organization might have higher expenses, which would offset the decreased price.

The UAV FSCM is not very sensitive to the number of people deployed for each mission (Figure 8-9). Adding two additional people to every mission increases FSCM by 8%.

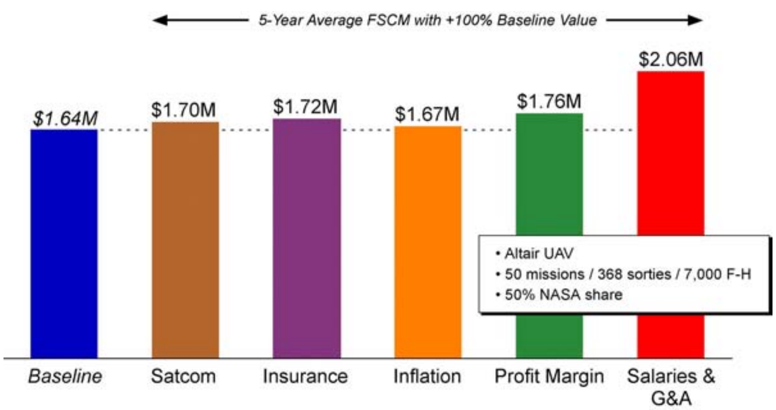


Figure 8-8. Effect of 100% Increase in Expenses and Profit Margin on FSCM

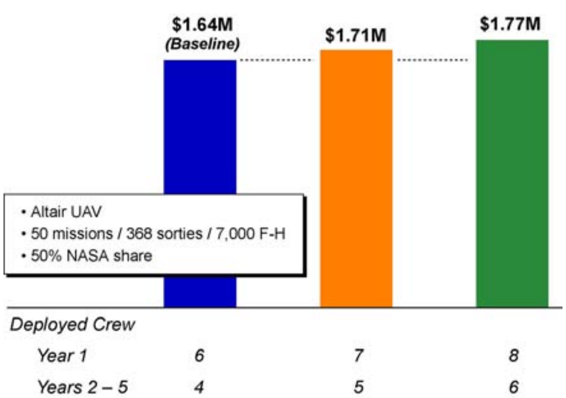
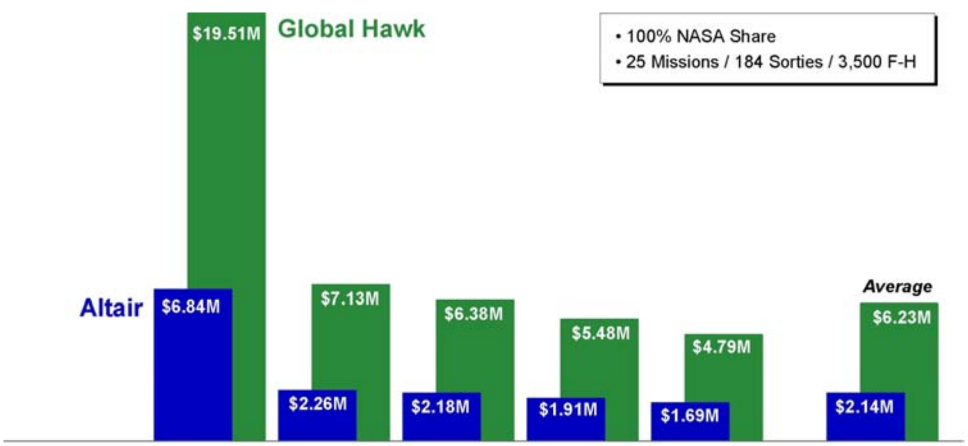


Figure 8-9. Impact of Deployed Crew on FSCM

8.4 Global Hawk

Using the larger Global Hawk instead of the Altair results in 191% higher FSCM, assuming each UAV performs 25 missions over five years (Figure 8-10). In Year 1, the Global Hawk costs $19.5 million per mission ($348,000 per flight-hour). In Year 2, the cost drops to $5.33 million per mission. The five-year average is $6,233,000 per mission.



	Year 1	Year 2	Year 3	Year 4	Year 5	Total
NASA Missions	1	3	6	7	8	25
Sorties Flown	4	18	42	56	64	184
Flight-Hours	56	288	756	1120	1280	3500

Figure 8-10. Comparison of Altair and Global Hawk FSCM over 25 Missions

Increasing the Global Hawk depreciation period to 10 years results in a 28% reduction in UAV FSCM.

The Global Hawk carries 2,000 lb of payload, about 2.7 times more than an Altair UAV. Over 25 missions, the Global Hawk costs approximately $22 per flight-hour per pound of payload (Figure 8-11). The Altair costs about 10% less for the same number of missions. With this metric, NASA's manned aircraft cost much less. The DC-8 costs $0.30 per flight-hour per pound of payload.

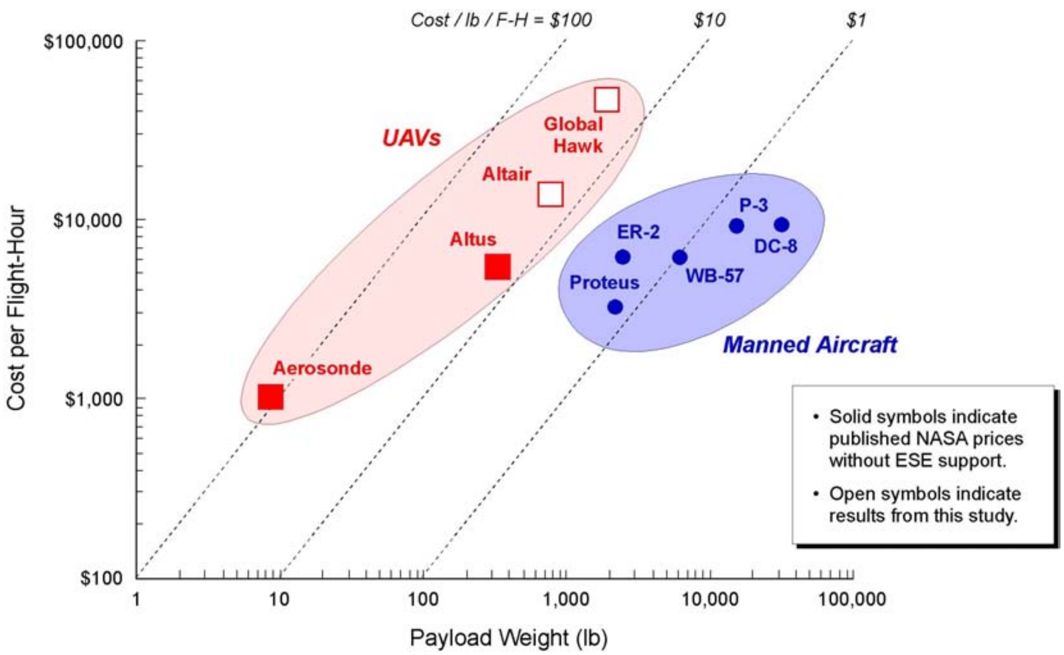


Figure 8-11. Comparison of Aircraft Mission Costs per Flight-Hour per Pound of Payload

If surplus Global Hawk UAVs were available *at no cost,* the FSCM is 70% lower. A Global Hawk mission costs $5.50 million in Year 1. The five-year average for 25 missions is $1.89 million compared to $2.14 million for a company-owned Altair flying the same number of missions.

An important difference is that it is unlikely a Global Hawk can fly more than 25 science missions over five years. An Altair can and probably would. If the Altair flew 50 missions over five years (the Baseline Case), its FSCM would average $1.64 million.

9. Evaluation of Alternative Business Models

Of the six alternative business models, a for-profit flight service that uses company-owned UAVs has the highest price in Mid-50 Utilization Scenario (Table 9-1). If the flight service can find a leasing company *that has enough confidence in the market to sign a five-year lease,* then the five-year average FSCM is less than if government owns the UAVs and ground equipment. The cost advantage to NASA for a business model with equipment leasing is sensitive to the lease term. If the flight service has a one-year lease, its prices would increase 41%.

		UAV Owner		
		Government	Leasing Company	Flight Service
UAV Operator	Non-profit Organization	**$1.52M** *$0.68M if equipment is free*	**$1.29M**	**$1.52M**
	For-Profit Company	**$1.57M** *$0.73M if equipment is free*	**$1.38M** *$1.95M with one-year lease*	**$1.64M** *$1.28M with 10-year depreciation*
50 Missions / 368 Sorties / 7,000 Flight-Hours · 50% NASA Share (25 Missions) · Altair UAV				

Table 9-1. Comparison of Alternative Business Models for the Mid-50 Utilization Scenario

The preference for leasing does not change with the number or NASA's share of missions sold (Table 9-2). Business models with leased equipment (with five-year leases) have lower FSCMs, even if NASA is the only customer.

There are very small differences in the FSCM for a for-profit company and a non-profit organization, assuming both have equal expenses. This is probably an optimistic assumption for the non-profit flight service. A for-profit company is generally more motivated to minimize expenses *and to attract new customers*. The result would be lower prices for all UAV flight service customers.

		UAV Owner		
		Government	Leasing Company	Flight Service
UAV Operator	Non-profit Organization	**$2.00M**	**$1.67M**	**$1.99M**
	For-Profit Company	**$2.04M**	**$1.80M**	**$2.14M**
25 Missions / 184 Sorties / 3,500 Flight-Hours · 100% NASA Share (25 Missions) · Altair UAV				

Table 9-2. Comparison of Alternative Business Models for the Low-100 Utilization Scenario

10. Technologies for Future Cost Reductions

As part of its program to transition to UAV flight services, NASA could identify technology improvements that have the potential to reduce far term UAV science mission costs.

The most apparent need is to *reduce requirements for OTH communications*. This can be accomplished by exploiting low cost satellite communications services, such as Iridium or Boeing's new Connexion service. Other possibilities include advanced data compression to reduce bandwidth requirements and using low frequency portions of the radio spectrum. Increased autonomy and data storage might significantly reduce OTH communications bandwidth requirements.

Improved UAV reliability will lower operating costs and reduce insurance costs. This may be possible by innovative applications of advanced sensors, adaptive controls, and self-healing components.

A breakthrough in reducing the cost of UAV science missions may be possible with the next generation of small long endurance UAVs. Improved capabilities are anticipated because sensors and avionics are getting smaller, and air vehicles are becoming more efficient (Hudson, 2003). Soon, small UAVs may be able to operate in the stratosphere, rivaling the range and endurance of larger HALE UAVs. A more significant breakthrough may be possible with the convergence of these improvements *and* new command and control technologies. These include autonomous control, multi-vehicle intelligence, and simplified operator interfaces. The result could be a new class of low cost vehicles that can be *operated by science personnel with minimal training*. This creates the potential to get large numbers of vehicles into the science community.

11. Conclusions

1. Civil science missions do not efficiently use manned or unmanned aircraft. This is the inherent nature of conducting experimental science. Science aircraft are committed for long periods to install and remove payloads. They fly relatively few hours. Using standardized payload pods and pallets will reduce upload and download time and cost, and allow the aircraft to be flown more often.

2. UAV civil science operations are, and will remain, a niche market in the US. In FY2005, NASA's spending on UAVs may be less than 1% of what DoD spends. Most US UAV manufacturers, including those that once focused on civil UAVs, are now focused on building military business. Increased UAV spending by the Department of Homeland Security may further divert industry attention from NASA programs.

3. Past UAV science mission costs do not reflect the true cost of UAV operations. NASA has primarily used developmental UAVs for science missions. Past NASA UAV mission costs have not included amortization of vehicle and ground station acquisition costs. These costs must be recovered by a commercial UAV flight service. Amortization (or lease) costs will be about 50% of a commercial UAV flight service's expenses.

4. Evaluating UAV-related science mission costs in terms of marginal cost per flight-hour ignores most of UAV-related costs. For science missions, the UAV marginal cost per flight-hour is only 25 – 30% of total cost for flight services. The remainder is mostly mission peculiar costs. A more useful cost metric is *flight service cost per mission,* which includes marginal operating costs and mission peculiar costs.

5. There may be near term opportunities to reduce UAV flight service costs. Insurance costs might be reduced by increasing awareness and stimulating competition in the insurance industry. This will require NASA outreach to the aviation insurance industry. Lower satcom costs might be possible by leveraging GSA and DoD satcom service contracts.

6. Providing NASA PIs with better business information and resources should help them obtain higher quality UAV flight services at a lower price. Standardized cost reporting can create information that PIs and NASA managers can use to reduce uncertainty in cost estimates and obtain better prices for flight services. A network of advisors might also be helpful.

7. No one type of UAV can satisfy most of the anticipated demand for science missions. Requirements range from Aerosonde to Global Hawk-class UAVs. Some UAV demand for shorter endurance missions is now being satisfied with new manned aircraft, such as the Proteus.

8. The High Altitude, Long Endurance (HALE) regime is the only practical niche for NASA to transition to UAV flight services. Aerosonde Pty. Ltd. is already providing flight services for small long endurance UAVs. CIRPAS is satisfying needs for mid altitude UAVs.

9. Altair is the only HALE UAV available from US industry that is practical for near term airborne science missions. This reinforces GA-ASI's dominant market position. Any plan for transition to commercial flight services must consider how GA-ASI will respond.

10. A commercial (for-profit) HALE UAV flight service provider using the Altair is a viable approach to satisfy NASA's emerging science needs. A non-profit flight service might have somewhat lower prices for NASA, but has greater uncertainty in long term service quality and operational capability.

11. Flight service costs are sensitive to UAV and ground equipment acquisition costs. Competition among UAV manufacturers is desirable. If this is not possible, other innovative approaches might be possible, such as equipment leasing. If cost reimbursement contracts are used, the flight service provider might be able to lower prices by extending the period over which equipment acquisition costs are depreciated.

12. Making multi-year commitments for UAV flight services will lower costs. This would allow a UAV flight service provider to sign long-term leases for its UAVs and ground equipment, which should reduce annual expenses. Conversely, short-term lease would probably result in substantially higher flight service costs.

13. Global Hawk flight service costs are about three times higher than Altair, if both aircraft fly the same number of missions. Global Hawk may have more payload capacity and performance than needed to satisfy most science requirements — unless it replaces the ER-2. Using Global Hawk for UAV science missions will involve managing multiple payloads on one flight. Today, this capability only resides in the government. Transferring this capability to a commercial flight service may involve significant cost and technical risk.

14. NASA's airborne science program could establish technology goals that lead to significant long-term reductions in UAV flight service costs. Possible goals are reducing the required bandwidth for over-the-horizon communications, developing innovative ways to exploit new low cost satellite communications services (such as Connexion by Boeing^{SM}), and improving UAV reliability. Technological synergies in the next generation of small UAVs could lead to a substantial reduction in UAV science mission costs.

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Appendix A: UAV Science Mission Cost Template

	Phase						
	Pre-Mission	Mission					Post Mission
		Upload	Transit Out	Flight Operations	Transit Back	Download	
Description	**Coordination with PI, Regulatory Agencies, and Mission Site**	**Planning; Payload Engineering & Installation; & Verification**	**Equipment Packaging, Shipping, & Personnel Transportation**	**Deployment and Flight Operations at Mission Site**	**Equipment Packaging, Shipping, & Personnel Transpiration**	**Payload Removal & Verification**	**Documentation & Support to PI**
UAV Use							
Ground Equipment Use							
Facilities Use							
Burdened Labor							
Per Diem & Related Costs							
Flight Consumables							
Communications Services							
Insurance							
Transportation							
Other Material & Services							

Appendix B: US Aviation Insurance Underwriters

Aerospace Insurance Managers, Inc.
14850 Quorum Suite 150
Dallas, TX 75254
972-852-1200
www.aerospaceim.com

AIG Aviation
70 Pine Street
New York, NY 10270
602-922-7117
www.aigaviation.com

Global Aerospace Underwriting Managers
51 JFK Parkway
Short Hills, NJ 07078
973-379-0800
www.global-aero.com

London Aviation Underwriters, Inc.
226 Second Avenue W.
Seattle, WA 98119
206-285-5401
www.londonaviation.com

United States Aircraft Insurance Group
Los Angeles Branch
626-577-6333
www.usau.com

U.S. Specialty Insurance Company
16415 Addison Road, Suite 900
Addison, TX 75001
972-447-2000
www.ussicaviation.com

W. Brown and Associates
19000 MacArthur Boulevard
Suite 700
Irvine, CA 92612
949-851-2060
www.wbais.com

Appendix C: Predator B Costs

	FY04	*FY05*	*Total*	*Average*
Basic UAV				
Quantity	6	2	8	
Cost ($M)	50.494	19.512	70.006	8.75
Ground Equipment				
Control Station				
Quantity	9	6	15	
Cost ($M)	28.747	17.867	46.614	3.10
Communications				
Quantity	7	4	11	
Cost ($M)	12.440	8.568	21.008	1.91
Deployment Kits				
Quantity	5	4	9	
Cost ($M)	20.251	19.162	39.413	4.38

Source: FY 2005 President's Budget Submission (Feb 2004)

Appendix D: WingsAbout Assumptions – Baseline Case

- Altair UAV
- FSCM based on cost-reimbursement contracts
- No UAV accidents

Flight Operation Weeks Per Mission	4
People Deployed per Mission	6 in Year 1; 6 in Years 2–5
Satcom	Average of $420 per flight hour
Altair and Ground Equipment Support	$5,000 per week plus 0.3% of the equipment value
Flight Consumables	$150 per flight-hour
Personnel Travel-Related Costs	$1,500 per week for each deployed person
Annual Unit Maintenance Cost	
Altair	2% of purchase price
Ground Equipment	1% of purchase price
Unit Purchase Price	
Altair	$8,000,000
Ground Equipment	$6,000,000
Inflation Rate	2%
Depreciation Period	
Altair	5 years – straight-line method
Ground Equipment	5 years – straight-line method
Interest Rate	6%
Loan Term	
Altair	10 years
Ground Equipment	10 years
Lease Term	5 years
Profit Margin	5%
Tax Rate	30%
Hull Replacement & Liability Insurance	2% of UAV replacement value plus 0.5% of ground station replacement value plus $30,000 mission
Compensation per Employee	$65,000 plus inflation
G&A Expenses per Employee	$55,000 plus inflation